Effect of proprioceptive vibrations on simulator sickness during navigation task in virtual environment

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Abstract

In virtual reality the navigation task can generate motion sickness also called simulator sickness or cyber-sickness. This in mainly due to the lack of sensory feedbacks during the task. The presented work aims at studying proprioceptive vibrations for improving the navigation task, decreasing simulator sickness and improving the sense of presence. In this study, proprioceptive vibrations are used to stimulate the lower gluteus maximus muscles during the avatar displacement in the virtual world. The experiment shows the impact of proprioceptive vibrations on navigation task.

Categories and Participant Descriptors: H.5.1 [Information Interfaces and Presentation (e.g., HCI)]: Multimedia Information Systems — Artificial, augmented, and virtual realities H.5.2 [Information Interfaces and Presentation (e.g., HCI)]: User Interfaces — Haptic I/O

1. Introduction

Virtual reality enables the immersion of a user in a virtual world to safely perform full scale actions. In industry, virtual reality is used to evaluate product along the design process. The major advantage of virtual reality is to explore an infinite virtual worlds in a small space. To access to the whole infinite virtual world a Human Machine Interaction is needed. Therefor we use metaphors to navigate through the virtual world. When navigating in virtual world cyber-sickness effects can appear. This in mainly due to the lack of sensory feedbacks during the task. A virtual reality application is multimodal, it is possible to add a new dimension to these applications to reduce simulator sickness due to navigation and allows at the same time to improve the sense of presence felt by users. Proprioceptive vibrations allow feeling imaginary movement. Therefore the objective of this research is to assess to what extent proprioceptive vibrations can help the navigation in a virtual environment.

2. Navigation in virtual environment

2.1. Navigation

Navigation is the task that corresponds to the execution of an action that drives us to go from our current location to a new target location [BOL80] [PCY*06]. In the real environment, movement is made as evidence, it is an act of unconscious cognition. Therefore, it is essential that the movement in virtual environment is close to movement in the real world. The user may need to move in virtual environment for many reasons. The understanding of the different types of motion tasks is important because the user of a particular technique often depends on the task for which it is used. The navigation is a common task for numerous applications of virtual reality even if the main objective of the application is different from moving.

Navigation includes tasks "way finding" and displacement. The "way finding" is the cognitive element of navigation. It involves no movement but only tactics and strategy to guide the movement to the desired location [WJ88]. Navigation users behavior has been widely studied [WSW*97] [WSW*06] [WB95]. To navigate, users provide their movement using a mental map of the environment based on the spatial knowledge acquired during the immersion. However, the acquisition of these data is more or less long and hence, users are not always willing to spend the time on this acquisition. This is why virtual reality interfaces provides guidance to help the user to orient them. Without this information, the user is confused.

It is very important to know how we can reach the target location. Some parameters such as velocity and acceleration have an effect on the user. For example, too high speed or sudden movement variations thereof can cause the simulator sickness.

To navigate through the virtual world we can use many devices like gamepad, flystick, treadmill, motion capture … For all devices it's needed to develop a metaphor. In fact the movement made to navigate in the virtual world can not be the same movement done to move in the real world. In fact the real world is most of the time smaller than the virtualized world.

To evaluate the navigation task performance we have to use parameters reflecting the participant capability to control his avatar during the displacement. Thus, it is relevant to measure the trajectory and the time the participant do while following a special navigation task. For example, this task may be a slalom. Participant trajectory can be compared to a reference trajectory as a performance indicator.

2.2. Proprioception

Proprioception allows to know the position of our body in space at any time. Several organs are involved in the principle of proprioception as the inner ears, viscera, skin, joints and muscle. In this study the muscle are our concerns. The muscles have muscle spindles that are located in major part to the junction between the tendon and the muscle fiber. During elongation of muscle, spindles send a signal between 70 and 90 Hz to the brain. This signal allows to know the position of the muscle and therefore the associated parts of the body.

3. Navigation perception

3.1. Sense of presence

In the literature there are three different approaches to the sense of presence in virtual reality. The first one is a technological approach. In this approach the sense of presence is seen as “been there feeling”, the user is outside of where he physically is, the "elsewhere" is formed by the images, sounds and physical sensations provided to the user’s senses by the system generating the virtual environment [SU93]. The second is a psychological approach where the sense of presence is not only dependent of the immersive system but is also a matter of perception of the environment [BIO03]. And the last one is an ecological approach. Presence is equivalent to successfully undertaken actions in the environment. If I can do in this environment then I exist therein [ZJ98].

The definition of presence that we hold for our study will be the one used by Bouvier [BOU09], the sense of presence: The authentic sense of existing in a world other than the physical world where our body is.

To measure the sense of presence, we use the presence questionnaire [WS98]. A questionnaire with 22 Likert scale questions is used. This questionnaire is divided in 5 factors, realism, ability to act, interface quality, performance self-assessment, and hearing.

3.2. Simulator sickness

Simulator sickness physiological symptoms are similar to motion sickness. Depending on the user, they can vary in shape, intensity and duration nausea, cold sweats, visual fatigue, dizziness, lightheadedness open or closed eyes, vomiting, etc. Similarly, the simulator sickness can be felt during and sometimes after exposure to the virtual environment. In some people, it can be felt even several hours after exposure [JOH05] [KF85] [KOL95] [LAV00].

One of the theories about the simulator sickness origin is given by Reason and Brand [RB75] who based their theory of sensory conflict on the conflict between the sensory stimulations and sensations expected by the user. This conflict may be due to a lack of sensory information or to inconsistency of sensory feedback.

Another theory about the Simulator sickness is given by Treisman [TR77]. He compare the simulator sickness to a food poisoning. Thus the body reactions are the same.

There are many ways to measure the cyber-sickness. In this study we use two methods. The first one is the SSQ from Kennedy [KLB*93] simplified by Bouchard [BRR07]. This questionnaire is composed by 16 questions divided in two factors, nausea and oculo-motor. The questions are answered on a 4 levels Likert scale.

The second method uses the Stoffregen theory on postural instability [SR91] [SHH*00]. Thus we measure the user postural stability before and after the exposure. The more the stability change, the more the participant is sick. To measure the postural stability, participants stand still 51.2 seconds on the balance. During this time, we calculate the trajectory of the participant gravity center projected on the floor. This trajectory can be surrounded by an ellipse. This ellipse give the postural stability surface in mm^2.

4. Scientific question

4.1. Vibration feedback

Muscle spindles can be excited by vibrators to simulate the pulses, they send to the brain during navigation. Thus, by vibrating these spindles and inducing a movement to the participant, it is possible to render a sensation of motion. The participant then thinks achieves the movement as he remains in place.

4.2. Question of research

The aim of this study to explore added value of proprioceptive vibrations for navigation in virtual environment. The question of research we intend to address is the following one:

What is the impact of proprioceptive vibrations used with speed control navigation in virtual environment?

The figure 1 illustrates the problematic.

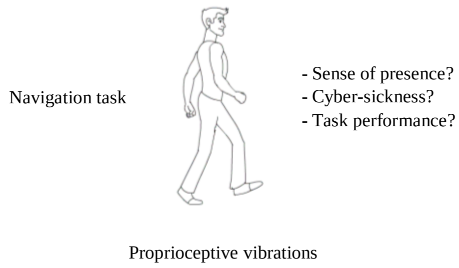

Figure 1*: Proprioceptive vibrations for navigation task*

4.3. Hypothesis

The hypothesis we want to validate are the following. We consider 3 possible different impacts of these vibrations on the participant and the simulation.

H1- They should impact the cyber-sickness and decrease it.

H2- They should impact the sense of presence and increase it.

H3- The navigation task performance should be impacted in a good way by the vibrations.

5. Experimental studies

5.1. Protocol

The simulation is made of two sequences. In the first sequence (Fig. 2 left), participants are asked to navigate on a path through a forest. They walk over 400 meters and the path contains turns. This sequence allows participants to learn the navigation interface and the vibrations feedback when they are activated. In the second sequence (Fig. 2 right), participants are put in front of a slalom represented by cones on the floor. They are asked to perform the slalom twice. During the second execution of the slalom, we measure the trajectory and the time made by the participant to do the slalom.

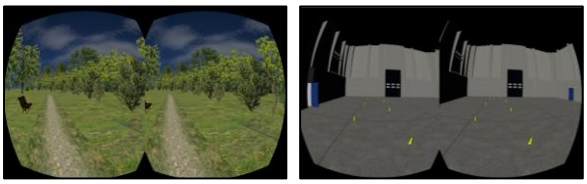

Figure 2*: The experiment two sequences*

To navigate, participants use the Hydra Joystick. The right joystick controls the translation of their avatar. A position of the joystick corresponds to a speed and a direction. The maximum speed is 1.7 $m.s^{-1}$. The left joystick is used to make the avatar's body rotating. The maximum rotate speed is $51°.s^{-1}$. Proprioceptive vibrations are activated when the participant avatar move.

The experimentation compare two conditions, the first condition is a simulation without vibration and the second use proprioceptive vibrations. Thus, participants have to do the simulation twice. To prevent accumulation effect of simulator sickness, participants have minimum one day between the two simulations. Conditions order is made randomly to avoid learning effect. Before performing experiments, participants complete the Immersive Tendency Questionnaire [WS95] to evaluate their immersion capability in virtual reality. For the two simulations, they answer the Presence Questionnaire [WS95] to evaluate their sense of presence during the simulation and they answer the simplified Simulator Sickness Questionnaire to evaluate their cyber-sickness level [KLB*93] [BRR07]. Furthermore, before and after each trial, participants will stand still on a "Stabilotest" stability measurement platform to define their postural stability before and after simulation.

5.2. Materials

5.2.1. Hardware

For this study we mostly use gaming hardware. The visual device we use is the head mounted display Oculus Rift DK1. It has a resolution of 1280 x 800, an orientation tracking and a FOV about 110°. For the navigation we use the gamepad Hydra from Razer. They have two analogic joystick, 8 buttons and 4 trigger. The device used to apply proprioceptive vibrations is home made. We use two Uni Vibe 45mm Vibration Motor - 28mm Type. They are powered by 2.4 Volt to provide a vibration of 80Hz. They are put in an ergonomic box fixed against the lower gluteus maximus muscles to provide an illusion of slight imbalance forward. To walk, we create an imbalance forward and our legs offset this imbalance. We then operate as an inverted pendulum. Thus the simulated imbalance correspond to the walking initialization movement. Motors are controlled by an Arduino interfaced by USB to the computer (Fig. 3).

Figure 3: *Proprioceptive vibrations devices on a participant*

5.2.2. Participants

A group of 18 participants did the experimentation, 2 participants didn't follow the experiment rules and 2 were too sick to finish the experiment. Thus 14 participants from 18 to 49 years old are selected to compute the results, 3 women and 11 men. Their mean capability to be immerged in the virtual reality is 72 with a standard deviation of 14. Seven of them weren't used to virtual reality. As evaluations are subjective, the participant answers can differ from one another from the same state of perception. Then it is more appropriate to compare the modalities participant by participant. Thus we use paired statistic tests such as the paired Wilcoxon test and the paired Student T test.

6. Results and analyses

6.1. Simulator sickness

In the figure 4 we can see the SSQ score (Fig. 3) for each participant. For each of them, the score decrease with proprioceptive vibrations. The paired comparison test of Wilcoxon signed-rank give a p value of $p=0.004 < 0.05$ that means the difference between the two modalities is significant.

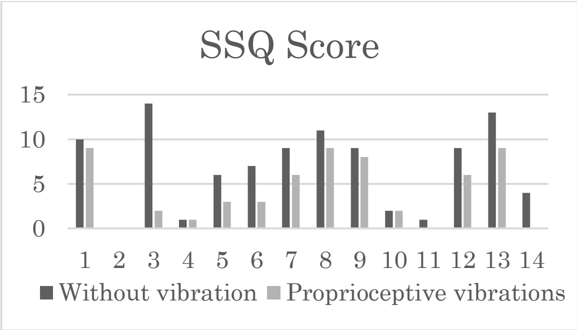

Figure 4: *SSQ Score*

The figure 5 shows the impact of the proprioceptive vibrations on the participant stability. The stability surface is sgnificantly less important with vibrations than without. The paired comparison student t test give a p value of $p=0.020 < 0.05$.

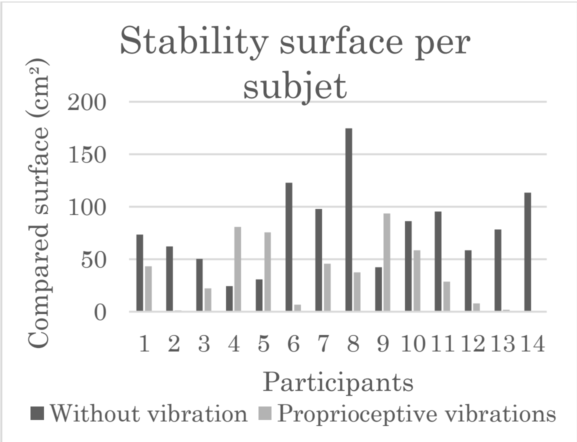

Figure 5: *Comparison of the surface stability*

6.2. Sense of presence

The figure 6 show the participant answers to the presence questionnaire. We can see that there is no real difference between the two modalities. The paired Wilcoxon signed-rank test confirms that observation giving a p value of $p=0.937 > 0.05$. So the difference is not significant.

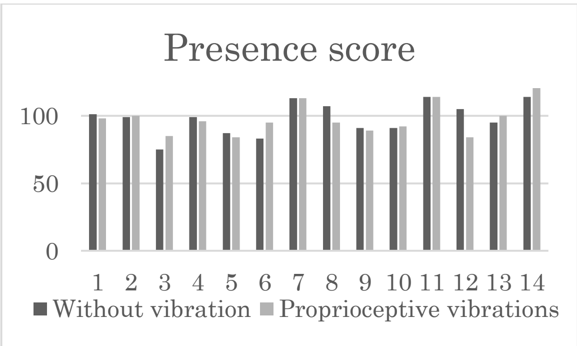

Figure 6: *Presence score*

6.3. Task performance

The next two figures show the task performance evaluation. The first (Fig. 7) shows the time to execute the slalom and the second (Fig. 8) corresponds to the surface between the real trajectory and a referential one. The paired student t test give a p value of $p=0.616 > 0.05$ for the time parameter and $p=0.572 > 0.05$ for the trajectory parameter. Both parameters do not change with the modalities.

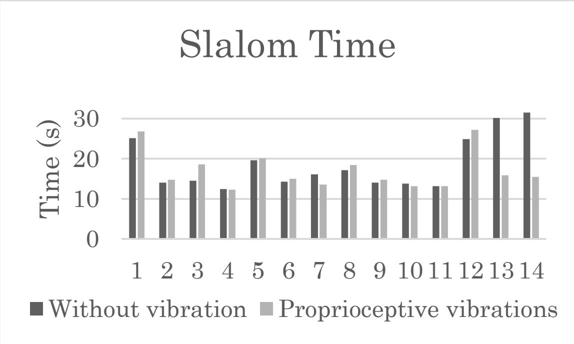

Figure 7: *Time to perform the slalom*

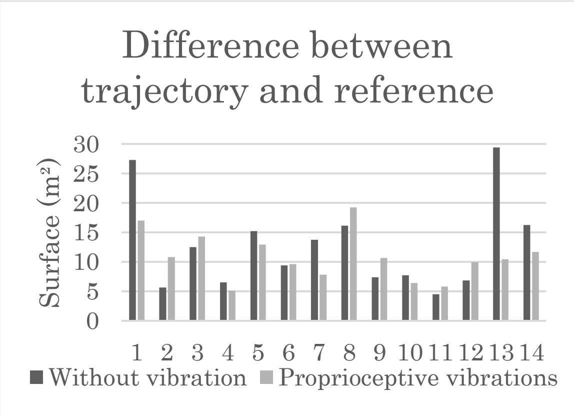

Figure 8: *Difference between trajectory and reference*

6.4. Analysis

The Simulator Sickness Questionnaire results and the postural stability results decrease with the proprioceptive vibrations and for each result, the difference between the modalities are significant. This prove the proprioceptive vibrations have an impact on the cyber-sickness. The proprioceptive vibrations used during the navigation help to decrease the cyber-sickness.

The presence questionnaire shows no difference between the two conditions (without vibration and with proprioceptive vibrations). As the difference is not significant, proprioceptive vibrations do not impact the sense of presence.

Performance evaluation shows also no difference. The proprioceptive vibration do not impact the navigation task performance.

7. Conclusion and future works

The aim of the study is to determine the impact of proprioceptive vibrations, added during the navigation task in virtual reality with a speed control navigation, on the sense of presence and the cyber-sickness. To answer the issue, we made an experimentation that allow the same group of participants to navigate through a virtual environment with and without proprioceptive vibrations.

The experiments could simply just not reveal a significant effect with their given p value or maybe the effect size is not big enough, or there is actually not a significant difference.

The results show that the proprioceptive vibrations have a good impact on the cyber-sickness. The level of simulator sickness decreases about 47% with the proprioceptive vibrations.

Results also show that proprioceptive vibrations have not impact on the sense of presence neither on the navigation performance. But the experiments could simply just not reveal a significant effect with their given p value or maybe the effect size is not big enough, or there is actually not a significant difference.

The study focuses on a speed control of the navigation. Future works will explode the effect of proprioceptive vibrations on other navigation parameters (such as acceleration control …). It would be interesting to test proprioceptive vibrations with other kind of navigation interaction such as virtual companion metaphor or grab the air navigation.

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